

Space heating models for residential buildings and the influence of urban variables

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Methodologies for energy performance assessment
based on location data

**Space heating models for residential buildings and
the influence of urban variables. The case study of
residential buildings in Turin (Italy)**

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research & innovation
energy
Department

JRC meeting
September 12-14, 2016

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Aim

Define energy consumption models at urban scale.
Understand how the urban context can influence the
buildings' energy consumptions for space heating



- ✓ Analyse the energy sustainability at urban scale, starting from the knowledge of energy consumptions of buildings (Cities on Power, Empowering, *QUADRANTE* and *EEB - Zero Energy Buildings in Smart Urban District*)
- ✓ Select, through a literature review, urban variables affecting space heating consumptions of residential buildings and
- ✓ Find the relationship to describe how energy consumption can vary with the urban context

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Energy consumption

$$\frac{kWh}{m^3} \Big|_{measured} = \frac{kWh}{m^3} \Big|_{building} \pm \frac{kWh}{m^3} \Big|_{context}$$



$kWh/m^3_{[building]} = f(\text{climate, compactness, period of construction, windows area, systems' efficiency, façades color...})$

$kWh/m^3_{[context]} = f(\text{urban form, materials of outdoor spaces, microclimate variations, ...})$

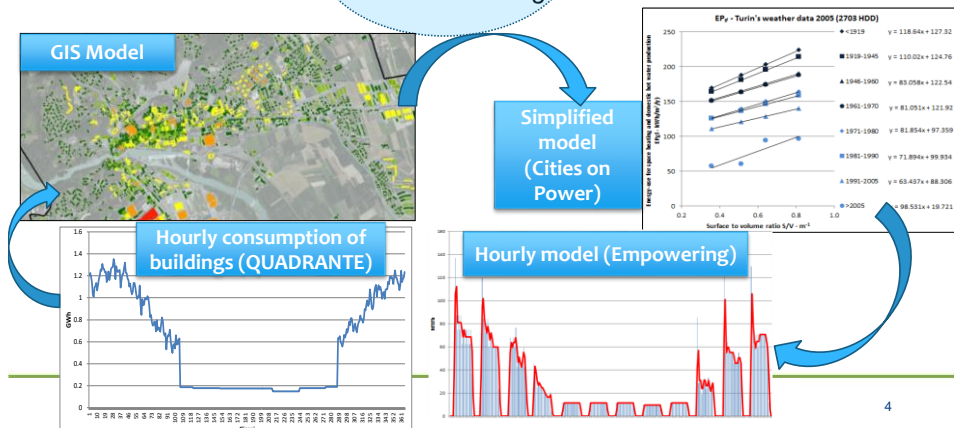
Territorial unit = census section or block of buildings

3

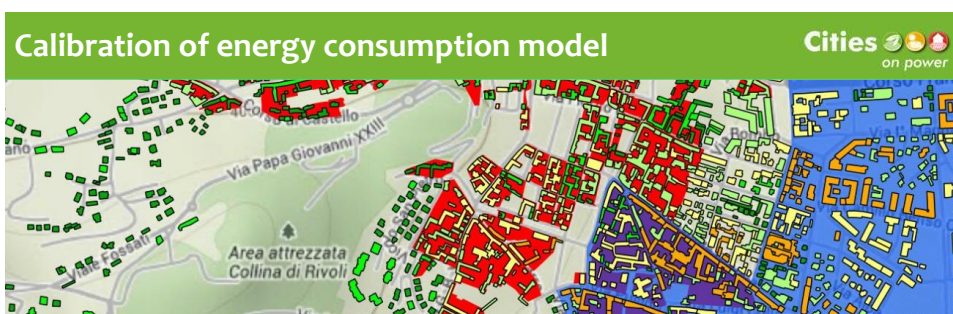
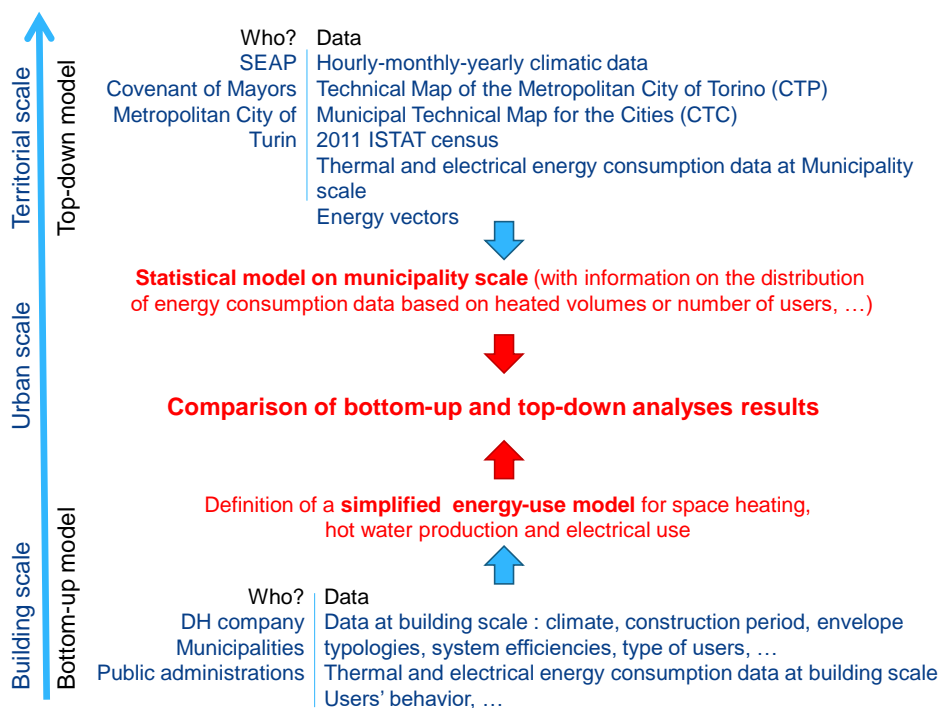
Cities
on power

Energy consumption models

$$\frac{kWh}{m^3} \Big|_{measured} = \frac{kWh}{m^3} \Big|_{building} \pm \frac{kWh}{m^3} \Big|_{context}$$



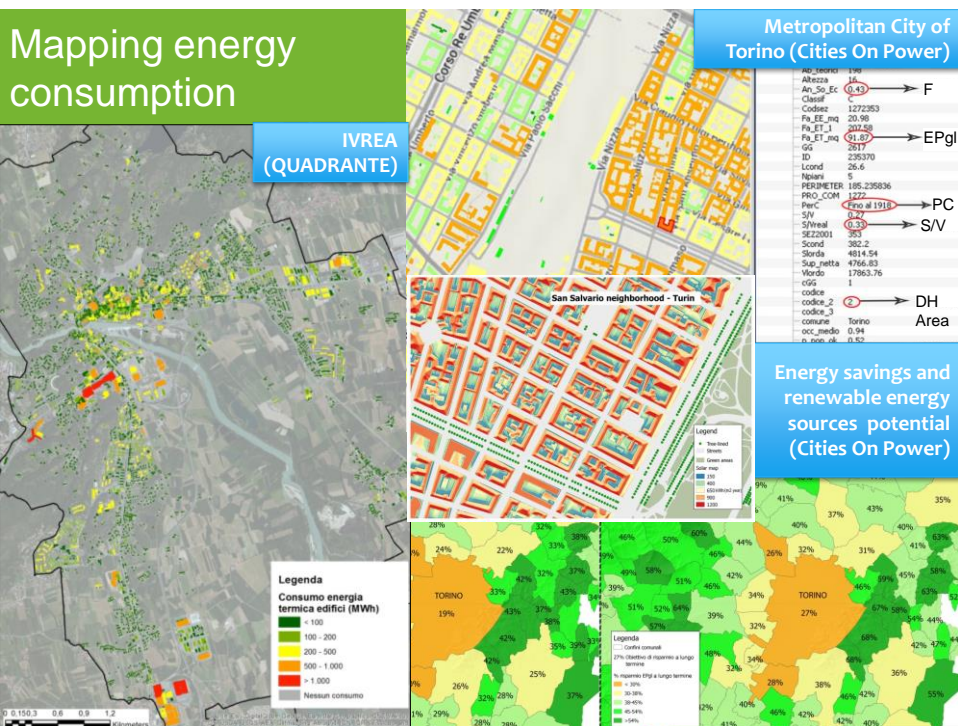
4



Definition of “correction” factor to consider at urban scale: urban constraints, buildings' energy renovation level, RES distribution, typology of user, ...

City	Volume of buildings (at 2005) Mm ³	Volume of buildings (2015) Mm ³	HDD (UNI 10349: 1994)	HDD (Reference year 2005)	HDD (last 10 years)	Heated volumes (ISTAT 2011)	Correction factor
Turin	160.55	163.36	2617	2703	2449	0.85	1.02

and “demographic” factors because energy-use models describe correctly the energy consumption of heated buildings but they do not fully understand the spatial variability of the heated and unheated spaces and the real extension of the indoor spaces.



Solar portal

<http://energia.sistemapiemonte.it/ittb-torino>

ACCESS

Manuale per l'utilizzo
(formato pdf 917 KB)

WEB interface with a cost-benefits analysis of solar RES

Cities	Buildings B (2010)	Apartments A (2010)	A/B	PV potential (MWh)	Electrical Energy-use EE (MWh)	PV/EE (%)
Baldissero T.se	1.103	1.658	1,50	5.007	5.147	97,3
Chieri	4.600	16.137	3,51	27.079	40.857	66,3
Grugliasco	2.255	16.797	7,45	9.777	38.248	25,6
Moncalieri	6.172	25.592	4,15	42.644	67.034	63,6
Nichelino	2.913	20.195	6,93	14.519	48.273	30,1
Pecetto Torinese	1.016	1.746	1,72	10.644	5.720	186,1
Pino Torinese	1.851	3.882	2,10	10.611	12.359	85,9
Settimo Torinese	3.506	20.265	5,78	13.931	47.829	29,1
Torino	35.804	439.251	12,27	228.794	1.091.375	21,0

Energy consumption

$$\frac{kWh}{m^3} \Big|_{measured} = \frac{kWh}{m^3} \Big|_{building} \pm \frac{kWh}{m^3} \Big|_{context}$$

urban form and materials:

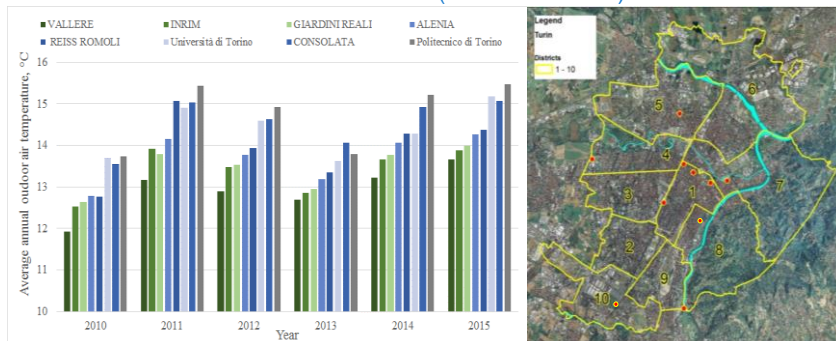


Space heating energy consumption and urban form. The case study of residential buildings in Turin (Italy) (SDEWES2016.0441), G. Mutani, A. Gamba, S. Maio, 11th Conference on Sustainable of Energy, Water and Environmental Systems, Lisbon, September 2016

Energy consumption

$$\frac{kWh}{m^3} \Big|_{measured} = \frac{kWh}{m^3} \Big|_{building} \pm \frac{kWh}{m^3} \Big|_{context}$$

microclimate variations (Turin 2450 HDD):



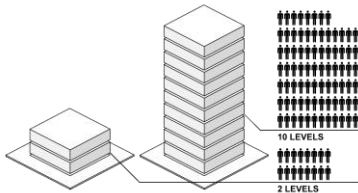
Urban planning for the liveability and thermal comfort of outdoor spaces (SDEWES2016.0442), G. Mutani, 11th Conference on Sustainable of Energy, Water and Environmental Systems, Lisbon, September 2016

Urban context variables

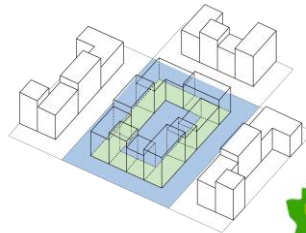
$$\text{kWh/m}^3_{[\text{CONTEXT}]} = f(\text{BD}, \text{BCR}, \text{H/W}, \text{H/Havg}, \text{MOS}, \text{A})$$

BD – Building Density [m^3/m^2]

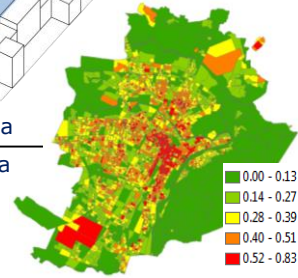
BCR – Building Coverage Ratio [m^2/m^2]



$$\text{BD} = \text{BCR} \cdot \text{Building Height}$$



$$\text{BCR} = \frac{\text{Built Area}}{\text{Site Area}}$$

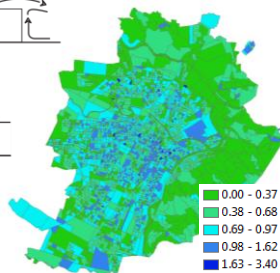
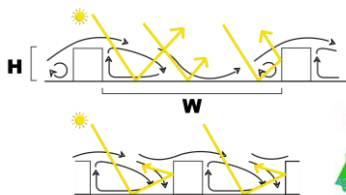


11

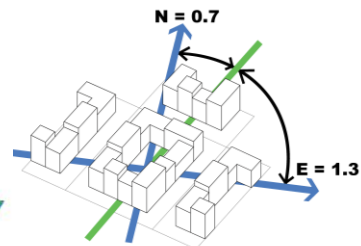
Urban context variables

$$\text{kWh/m}^3_{[\text{CONTEXT}]} = f(\text{BD}, \text{BCR}, \text{H/W}, \text{MOS}, \text{H/Havg}, \text{A})$$

H/W – Height to Distance or Aspect Ratio [m/m]



MOS – Main Orientation of Streets [-]

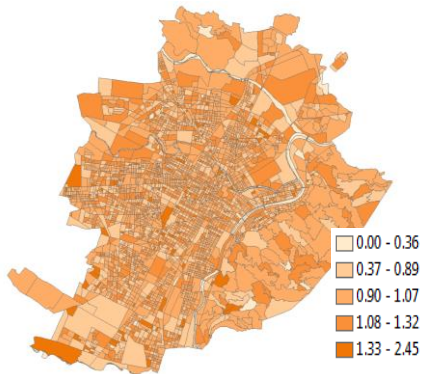


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Urban context variables

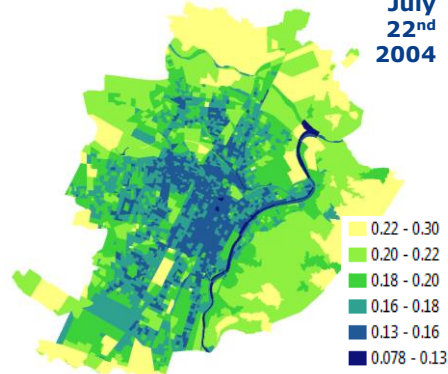
$$\text{kWh/m}^3_{[\text{CONTEXT}]} = f(\text{BCR}, \text{BD}, \text{H/W}, \text{MOS}, \text{H/Havg}, \text{A})$$

H/Havg – building relative Height [m/m]



A - Albedo [-]

ASTER
July
22nd
2004



Urban context factors

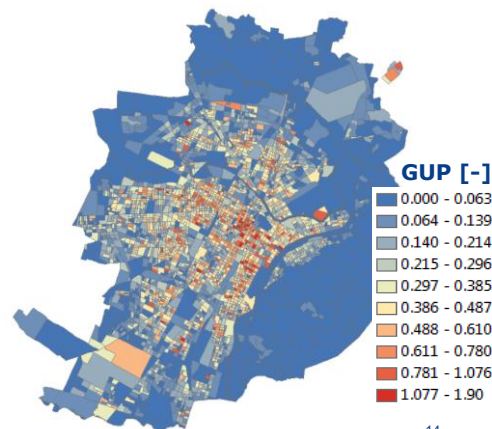
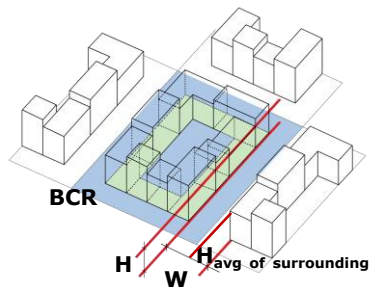
$$\text{GUPA} = \text{Global}(\text{U} \cdot \text{P} \cdot \text{A}) \quad [-]$$

Urban morphology factor

$$\text{U} = \text{BCR} \cdot \text{H} / \text{W} = \text{BD} / \text{W} \quad [-]$$

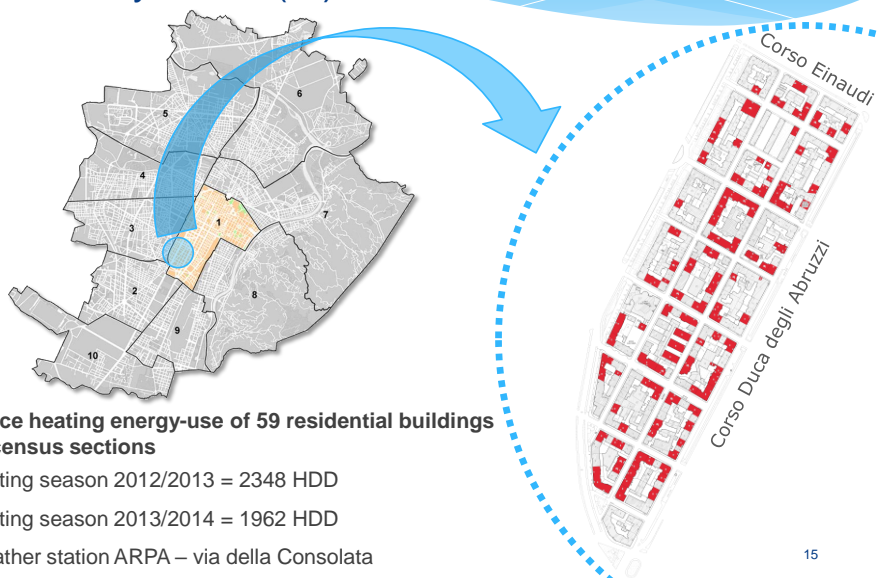
solar exPosure factor

$$\text{P} = \text{MOS} \cdot \text{H/Havg} \quad [-]$$



Case study: Turin (IT)

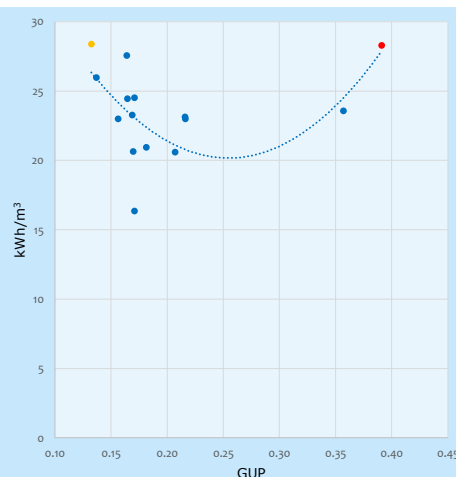
$$\frac{kWh}{m^3} \Big|_{measured} = \frac{kWh}{m^3} \Big|_{building} \pm \frac{kWh}{m^3} \Big|_{context}$$



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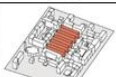



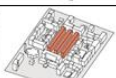



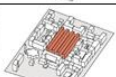



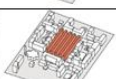




Energy consumption

Census sections	U [-]	P [-]	GUP [-]	kWh/m ³
1147	0.187	0.732	0.137	25.96
1149	0.259	0.651	0.169	23.26
1153	0.259	0.698	0.181	20.95
1154	0.140	0.943	0.133	28.40
1155	0.201	0.814	0.164	27.58
1160	0.170	1.005	0.171	16.34
1161	0.467	0.837	0.391	28.29
1162	0.184	0.893	0.164	24.45
1168	0.390	0.914	0.357	23.57
1169	0.239	0.713	0.171	24.52
1175	0.170	0.918	0.156	23.00
1181	0.235	0.722	0.170	20.64
1183	0.265	0.813	0.216	23.13
1188	0.276	0.783	0.216	23.00
1189	0.243	0.851	0.207	20.60



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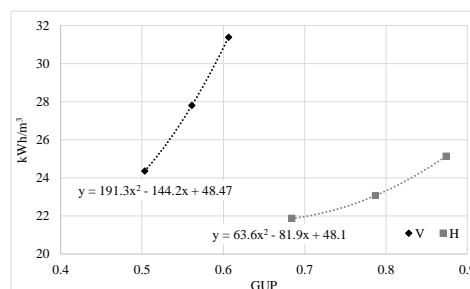
CitySim Simulations

		H1 H/W = 1.410 $x_{\text{ref}} = 11.74 \text{ m}$ $y_{\text{ref}} = 15.73 \text{ m}$ BCR = $0.387 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.26 m^2			BCR4 H/W = 1.009 $x_{\text{ref}} = y_{\text{ref}} = 21.99 \text{ m}$ BCR = $0.223 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.33 m^2	<p>Swiss Federal Institute of Technology Lausanne (EPFL)</p> <p>http://citysim.epfl.ch/</p>
		H2 H/W = 1.612 $x_{\text{ref}} = 11.74 \text{ m}$ $y_{\text{ref}} = 13.76 \text{ m}$ BCR = $0.387 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.27 m^2			BCR5 H/W = 1.009 $x_{\text{ref}} = y_{\text{ref}} = 21.99 \text{ m}$ BCR = $0.221 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.27 m^2	
		H3 H/W = 1.783 $x_{\text{ref}} = 11.74 \text{ m}$ $y_{\text{ref}} = 12.45 \text{ m}$ BCR = $0.387 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.30 m^2			BCR6 H/W = 1.009 $x_{\text{ref}} = y_{\text{ref}} = 21.99 \text{ m}$ BCR = $0.114 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.48 m^2	
		V1 H/W = 1.643 $x_{\text{ref}} = 13.50 \text{ m}$ $y_{\text{ref}} = 13.07 \text{ m}$ BCR = $0.387 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.29 m^2			BCR7 H/W = 1.009 $x_{\text{ref}} = y_{\text{ref}} = 21.99 \text{ m}$ BCR = $0.278 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.26 m^2	
		V2 H/W = 1.832 $x_{\text{ref}} = 12.11 \text{ m}$ $y_{\text{ref}} = 13.07 \text{ m}$ BCR = $0.387 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.35 m^2			BCR8 H/W = 1.009 $x_{\text{ref}} = y_{\text{ref}} = 21.99 \text{ m}$ BCR = $0.330 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.26 m^2	
		V3 H/W = 1.984 $x_{\text{ref}} = 11.18 \text{ m}$ $y_{\text{ref}} = 13.07 \text{ m}$ BCR = $0.387 \text{ m}^2/\text{m}^2$ BH = 22.19 m S/V = 0.41 m^2			BCR9 H/W = 1.009 $x_{\text{ref}} = y_{\text{ref}} = 21.99 \text{ m}$ $x_{\text{ref}} = y_{\text{ref}} = 55.73 \text{ m}$ BCR = $0.302 \text{ m}^2/\text{m}^2$ BH = 26.15 m S/V = 0.26 m^2	
						 R-BCR8 H/W = 1.009 $x_{\text{ref}} = y_{\text{ref}} = 21.99 \text{ m}$ BCR = $0.330 \text{ m}^2/\text{m}^2$ BH = 22.19 m BD = $7.33 \text{ m}^3/\text{m}^2$ S/V = 0.26 m^2
						 R-BCR9 H/W = 1.009 $x_{\text{ref}} = y_{\text{ref}} = 21.99 \text{ m}$ $x_{\text{ref}} = y_{\text{ref}} = 55.73 \text{ m}$ BCR = $0.302 \text{ m}^2/\text{m}^2$ BH = 26.15 m S/V = 0.26 m^2

census parcel 1168

Results

	S/V [m ²]	H/W [-]	MOS [-]	GUP [-]	Energy consumption [kWh/m ³]
H1	0.26	1.41	1.2	0.684	21.87
H2	0.27	1.61	1.2	0.787	23.07
H3	0.30	1.78	1.2	0.874	25.13
V1	0.29	1.64	0.8	0.503	24.36
V2	0.35	1.83	0.8	0.561	27.80
V3	0.41	1.98	0.8	0.606	31.37



BCR =

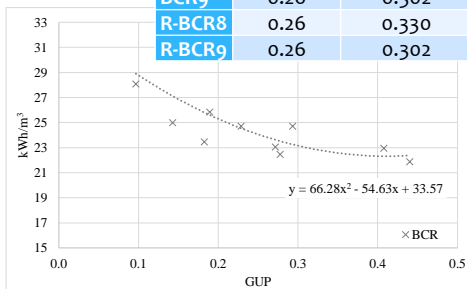
H/W =

kWh/m³ =

census parcel 1168

Results

	S/V [m ⁻¹]	BCR [m ² /m ²]	MOS [-]	GUP [-]	Energy consumption [kWh/m ³]
BCR1	0.40	0.113	0.8	0.097	28.07
BCR2	0.32	0.168	0.8	0.143	24.99
BCR3	0.29	0.223	0.8	0.183	23.46
BCR4	0.33	0.223	0.8	0.190	25.83
BCR5	0.27	0.221	1.2	0.278	22.45
BCR6	0.48	0.114	1.2	0.145	32.00
BCR7	0.26	0.278	0.8	0.229	24.71
BCR8	0.26	0.330	0.8	0.272	23.04
BCR9	0.26	0.302	0.8	0.294	24.71
R-BCR8	0.26	0.330	1.2	0.408	22.93
R-BCR9	0.26	0.302	1.2	0.440	21.87



H/W =

BCR ↑

kWh/m³ ↓

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Results

$$U_{optimal} = (BCR = 0.33) \cdot (0.9 < H/W < 1.1)$$

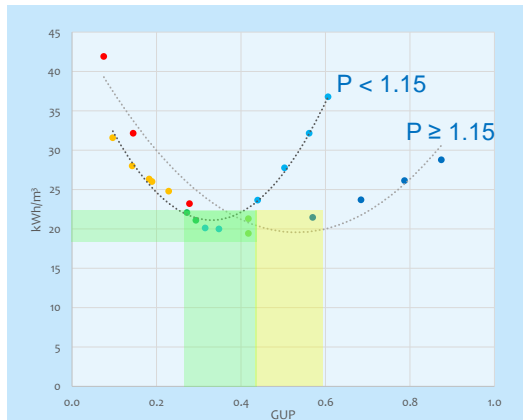
$$P_{optimal} = (H/H_{avg} > 1) \cdot (MOS > 1.15)$$

Solar factor	Urban Morphology factor UM and Heating Energy-use [kWh/m ³] _{avg}				
	U < 0.3		0.3 ≤ U ≤ 0.36		U > 0.36
P < 1.15	BCR1, BCR2 BCR3, BCR4 BCR7	25.41	BCR8 BCR9	23.88	V1 V2 V3 27.84
P ≥ 1.15	BCR5 BCR6	27.23	R-BCR8 R-BCR9	22.40	H1, H2 H3 23.36

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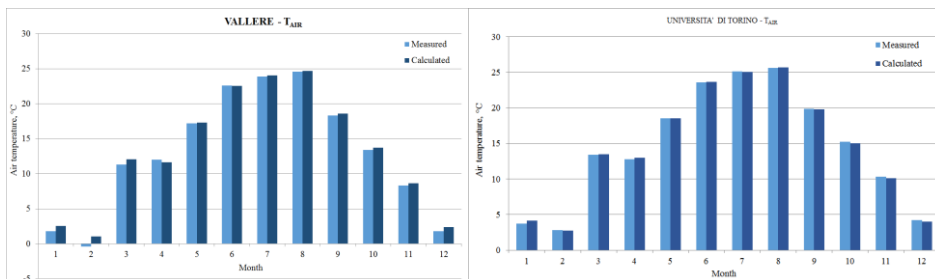
Conclusions

ASPECT RATIO, BUILDING DENSITY and SOLAR EXPOSITION



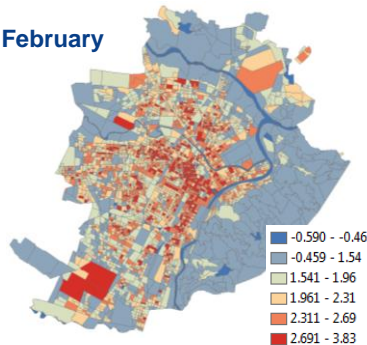
For Turin, the GUP optimal range is between 0.3 and 0.45 to ensure lowest consumptions. The presence of an optimal solar exposure allows to obtain acceptable energy consumptions also for higher GUP values.

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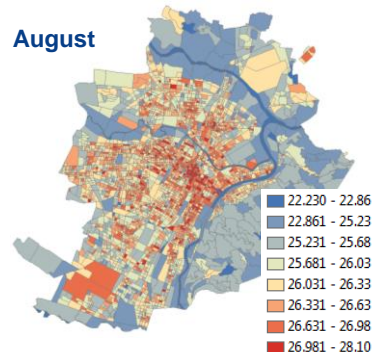


$$T_{\text{air}} = 23.05 \cdot G_{\text{mT}} + 2.69 \cdot \text{BCR} + 0.03 \cdot \text{H/W} + 0.65 \cdot \text{MOS} + 1.07 \cdot \text{H/H}_{\text{avg}} - 1.17 \cdot \text{A} - 0.6 \cdot \text{H}_2\text{O}$$

February



August



22

Smart cities need smart policies

Energy policies must be adapted to local needs and to environment characteristics: there is no one solution strategy!

The important role of urban planning, with urban morphology and solar exposure, in order to design more sustainable cities; the accuracy of methodologies and databases is crucial!

Future improvements:

- Analyse nZEBs with urban variables
- Evaluate different cities and climates
- Introduce the albedo coefficient, the presence of green areas, trees, rivers and lakes
- Analyse also space cooling energy consumptions
- Evaluate thermal comfort and the livability of outdoor spaces

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